

# RETRIEVAL OF PLANETARY ROTATION AND ALBEDO FROM DSCOVER DATA.

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## Introduction

The field of exoplanets has rapidly expanded from the exclusivity of exoplanet detection to include exoplanet characterization. This has been enabled by developments such as the detection of terrestrial-sized planets and the use of transit spectroscopy to study exoplanet atmospheres. The studies of rocky planets presently being undertaken are leading the path towards the direct imaging of exoplanets and the development of techniques to extract their intrinsic properties. The importance of properties such as rotation, albedo, and obliquity is significant since they are key input parameters for Global Climate Models used to determine surface conditions, such as the models of Forget & Lebonnois (2013). Thus, a complete characterization of exoplanets for understanding exoclimates requires the ability to obtain measurements of these key planetary parameters.

The retrieval of planetary albedos and rotation rates from highly undersampled imaging data can be informed by the use of climate satellites designed to study the Earth's atmosphere. The Deep Space Climate Observatory (DSCOVER) provides a unique opportunity to test such retrieval methods using data for the sunlit surface of the Earth. The high-resolution images can be deconvolved to match a variety of expected exoplanet mission requirements and the relatively high-cadence can be modified to design an effective observing strategy. Our modeling of the DSCOVER data will provide an effective baseline from which to develop tools that can be applied to a variety of exoplanet imaging data.

## The DSCOVER Mission

The DSCOVER mission<sup>1</sup> is primarily operated by the National Oceanic and Atmospheric Administration (NOAA). DSCOVER was successfully launched on February 11, 2015 via a SpaceX Falcon 9 rocket. The satellite reached the L1 Lagrange point between the Earth and the Sun on June 8, 2015. The satellite orbits the L1 point with a period of ~6 months resulting in an Earth-Sun viewing angle that varies in the range 4–15 degrees.

The details of DSCOVER hardware are shown in

<sup>1</sup><http://www.nesdis.noaa.gov/DSCOVER/>

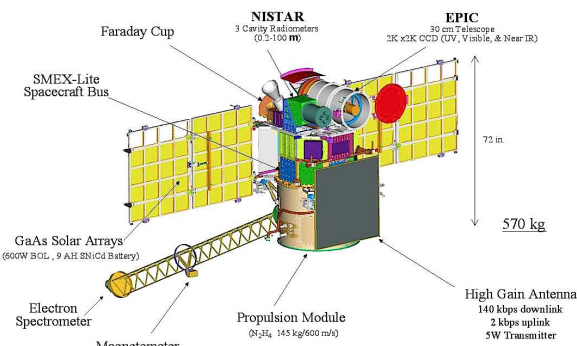


Figure 1: Earth-facing side of the DSCOVER satellite, showing the configuration of the instrumentation including the NISTAR and EPIC instruments described in this project.

Figure 1. There are two NASA instruments on board DSCOVER that are used to monitor the Earth in detail: the National Institute of Standards and Technology Advanced Radiometer (NISTAR) and the Earth Polychromatic Imaging Camera (EPIC). NISTAR consists of three active cavity radiometers and one silicon photodiode. The instrument uses three wide spectral bands to study the reflectance of the Earth: total radiation in the range 0.2–100 microns, reflected solar radiation in the range 0.2–4 microns, and reflected near-infrared radiation in the range 0.7–4 microns. The combination of these data enables monitoring of changes in Earth's total radiation budget.

EPIC is a 30 cm aperture f/9.6 Cassegrain telescope whose purpose is to take images of the sunlit side of the Earth. The EPIC field-of-view is  $0.61^\circ$  which, when coupled with the  $2048 \times 2048$  CCD, provides an angular resolution of 1.07 arcsec, or ~25 km/pixel surface resolution at a latitude  $60^\circ$  from the equator. A sample image from EPIC is shown in Figure 2 (left). The EPIC data are acquired from the spectroradiometer 10 narrowband channels in the range 317.5–780 nm with an exposure time of 40 ms. These passbands allow the investigation of specific surface and atmospheric features, such as  $O_3$ ,  $SO_2$ , aerosols at short wavelengths, and clouds/vegetation at long wavelengths.

The NISTAR and EPIC data products will be made

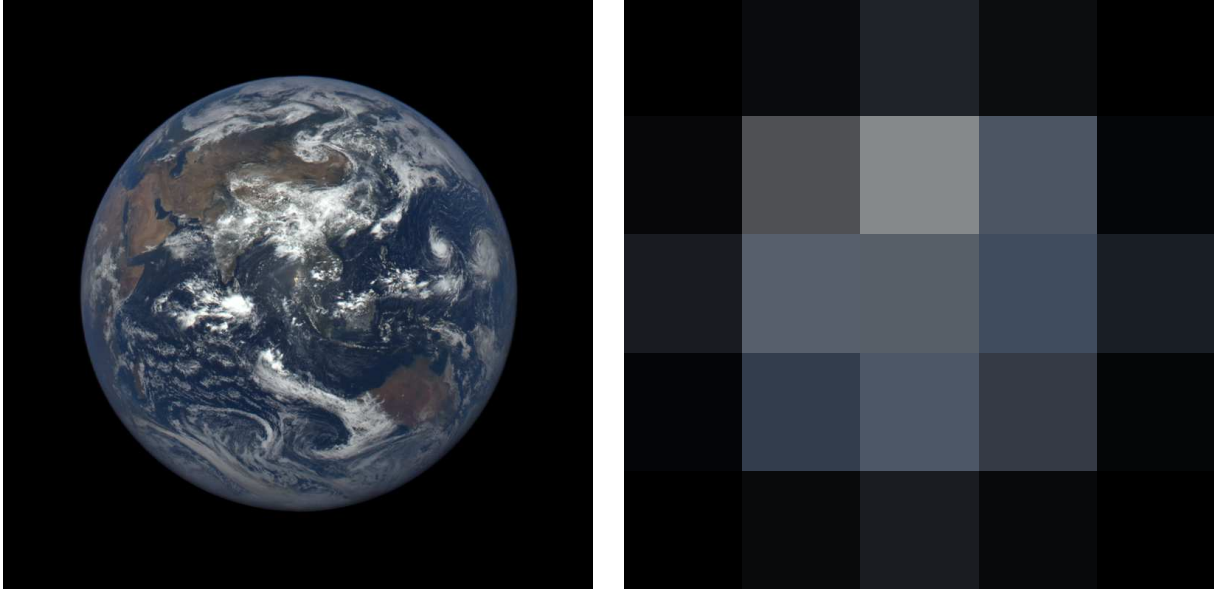


Figure 2: *Left: EPIC image of the Earth viewed from the L1 Lagrange point. The image was acquired on August 17, 2015 at 05:42:50 UT. Right: The same image as that shown at left after it has been deconvolved to  $5 \times 5$  pixel resolution.*

publicly available soon after they are acquired. All color images from EPIC are provided in high-resolution png format. The EPIC Level 1 (calibrated) individual wavelength images will also be provided when processing is complete. The data products may be acquired from the NASA Langley Atmospheric Science Data Center<sup>2</sup>.

### The Exoplanet Connection

The data from the DSCOVR mission provides a unique opportunity to monitor the Earth as an exoplanet for an extended period of time. A critical aspect of informing mission design for future NASA exoplanet imaging instruments is determining the limits of planetary parameter retrieval from severely undersampled data. Studies using limited datasets of Earth images have been performed by Cowan & Strait (2013) and Pallé et al. (2008). Our team are addressing this issue by deconvolving EPIC images to resolutions of only several pixels, with the inclusion of gaussian filters to account for dispersion effects. Figure 2 (right) shows an example of a  $5 \times 5$  pixel deconvolved image produced from a full-resolution EPIC image. We generate time series for each pixel in the deconvolved images and use fourier analysis techniques to extract periodic behavior due to planetary rotation, weather patterns, and surface terrain. We further measure the albedo from each deconvolved image which is then compared with the integrated radiance measurements from NISTAR observations. The time variance for each of the pixels, in particular the

asymmetry of the data from each hemisphere, are also used to place constraints on the obliquity of the planet. Through this methodology, we are creating a grid of retrieval rates as a function of image resolution, observing cadence, passband, etc.

There are various caveats that we are also taking care to account for in our analysis. Perhaps the most obvious is that the data we are using is specific to the Terran atmosphere. Results from the Kepler mission are revealing a continuum of terrestrial planetary sizes and masses (Burke et al. 2015), and there is likely a similar continuum of atmospheric parameters, including composition, mass, and dynamics. We thus are carefully considering how the results of this work will vary with different planetary and atmospheric properties. Due to the orbital motion of DSCOVR around L1, our analysis takes into account both the change in the Earth viewing angle and the angular size of the Earth-disk in the field-of-view. Finally, the orbital inclination of an exoplanet relative to line of sight will play a significant role in the observed analogous signature. The planetary phase of the exoplanet as it orbits the host star will also modify the signature. Both of these will be included in our simulations by overlaying the night-side of the planet onto the Earth-disk prior to deconvolution.

### Conclusions

Exoplanet characterization is currently dominated by measurables such as orbital elements and the planetary mass and radius. The detection of basic atmospheric

<sup>2</sup><https://eosweb.lac.nasa.gov>

constituents has come into reach for those transiting planets sufficiently close to their host star with a relatively large scale height. Future direct imaging missions will open further doors into extracting the fundamental intrinsic properties of the planet that are key components in the modeling of their climates. These include the planetary rotation and obliquity, and atmospheric albedo. The parameter extraction techniques we are developing will be used to inform mission design constraints on the required cadence and image resolution needed to constrain these important planetary parameters.

## References

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